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303 – Physics for Engineers II - Laboratory

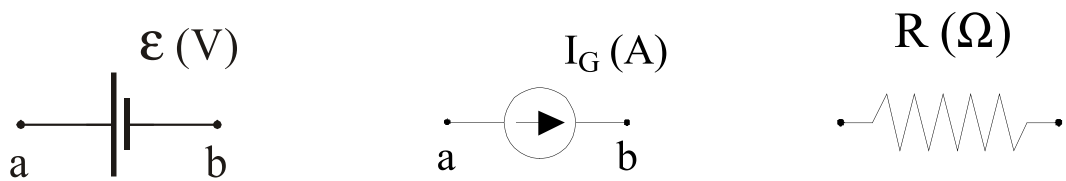
Experiment # 4: Simulation of electric circuits. Thévenin theorem

- **Electric network:** **nodes, branches, meshes, loops**
- **Kirchhoff rules**
- **Mesh analysis**
- **Thévenin theorem**
- **Circuit simulation software:** ***Electronics Workbench***

Basic definitions:

Electrical network: A number of elements connected together forming a set of interrelated circuits.

Active (source of energy) and passive elements (resistors, etc.):

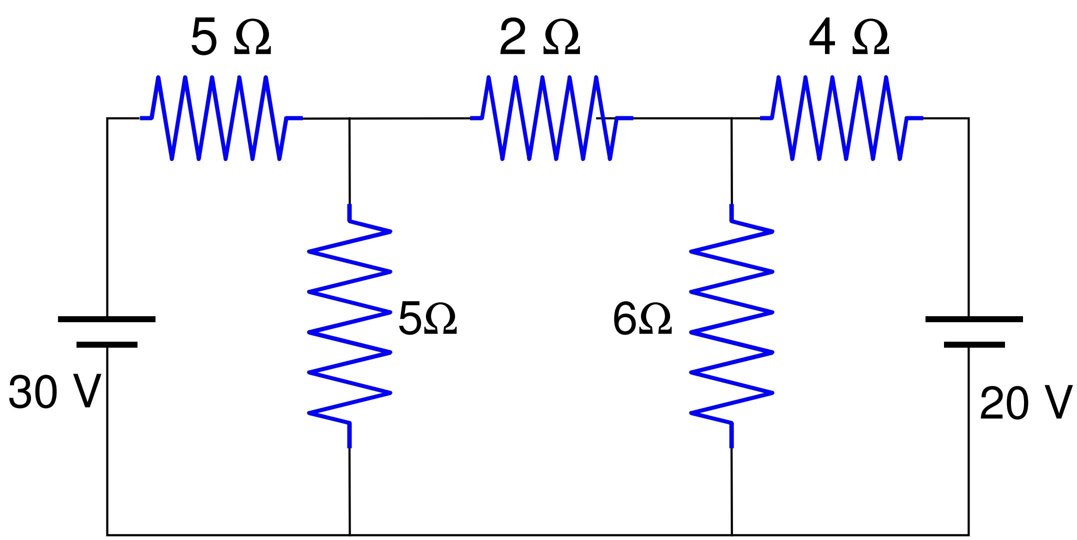


Node: Point where three or more circuit elements are joined together.

Branch: Conducting path between two nodes.

Loop: Any closed conducting path in the network.

Mesh: Loop of a circuit that does not contain any other loops within it.



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Kirchhoff's Laws of electric circuits

Junction rule (based on charge conservation), also Kirchhoff's current law (KCL):
In any junction of the circuit,

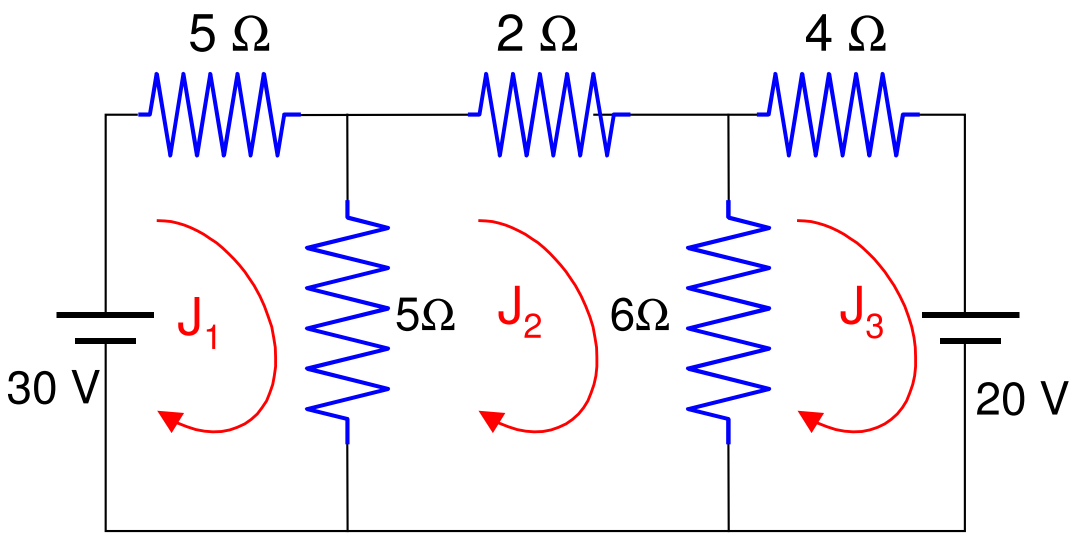
$$\sum i_{entering} = \sum i_{leaving}$$

Loop rule (based on energy conservation), also Kirchhoff's voltage law (KVL):
Around any closed loop in a circuit,

$$\sum_k \pm i_k R_k = \sum_k \pm \varepsilon_k$$

Sign convention:
Across a resistor, voltage drop >0 in the direction of i
Through a battery, potential difference >0 from + to – terminal

Loop rule



1. We choose a system of independent loops, including every branch in the circuit
2. We assign a number to each mesh, and choose an arbitrary current direction (same direction for every mesh, so opposite sign in shared branches)

3. We apply Kirkhhoff's loop rule, then we get n equations with n unknowns:

$$\sum_k (i_j - i_k) R_{jk} = \sum_k fem_{jk} \qquad {}_{j=1,2,\ldots}$$

Loop rule

$$\begin{pmatrix} R_{11}R_{12}\dots\dots\dots R_{1n} \\ R_{21}R_{22}\dots\dots\dots R_{2n} \\ \dots\dots\dots\dots\dots \\ R_{n1}R_{n2}\dots\dots\dots R_{nn} \end{pmatrix} \begin{pmatrix} J_1 \\ J_2 \\ \dots \\ J_n \end{pmatrix} = \begin{pmatrix} V_1 \\ V_2 \\ \dots \\ V_n \end{pmatrix}$$

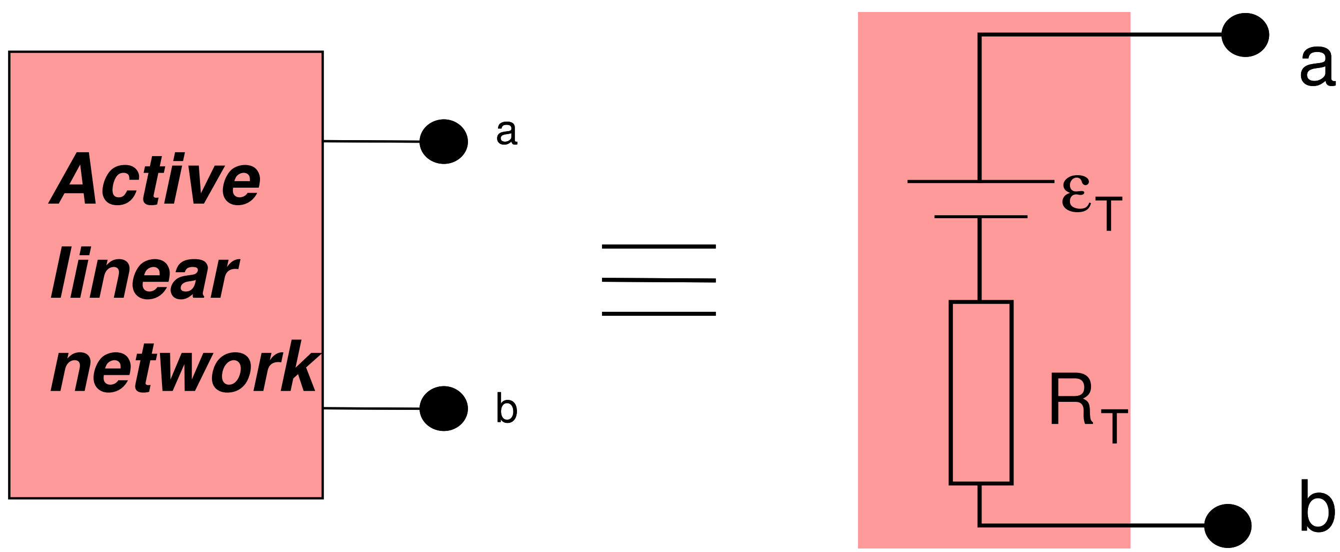
- R_{ii} sum of resistances in mesh *i*
- $R_{ij} = R_{ji}$ sum of resistances shared by meshes *i* and *j*, with opposite sign
- J_i current mesh *i*
- V_i sum of e.m.f. mesh *i*, with sign of exit pole

$$J_i = \frac{\begin{vmatrix} R_{11}R_{12}\dots\dots R_{1,i-1} & V_1 & R_{1,i+1}\dots\dots R_{1n} \\ R_{21}R_{22}\dots\dots R_{2,i-1} & V_2 & R_{2,i+1}\dots\dots R_{2n} \\ \dots\dots & \dots\dots & \dots\dots \\ R_{n1}R_{n2}\dots\dots R_{n,i-1} & V_n & R_{n,i+1}\dots\dots R_{nn} \end{vmatrix}}{\Delta_R}$$

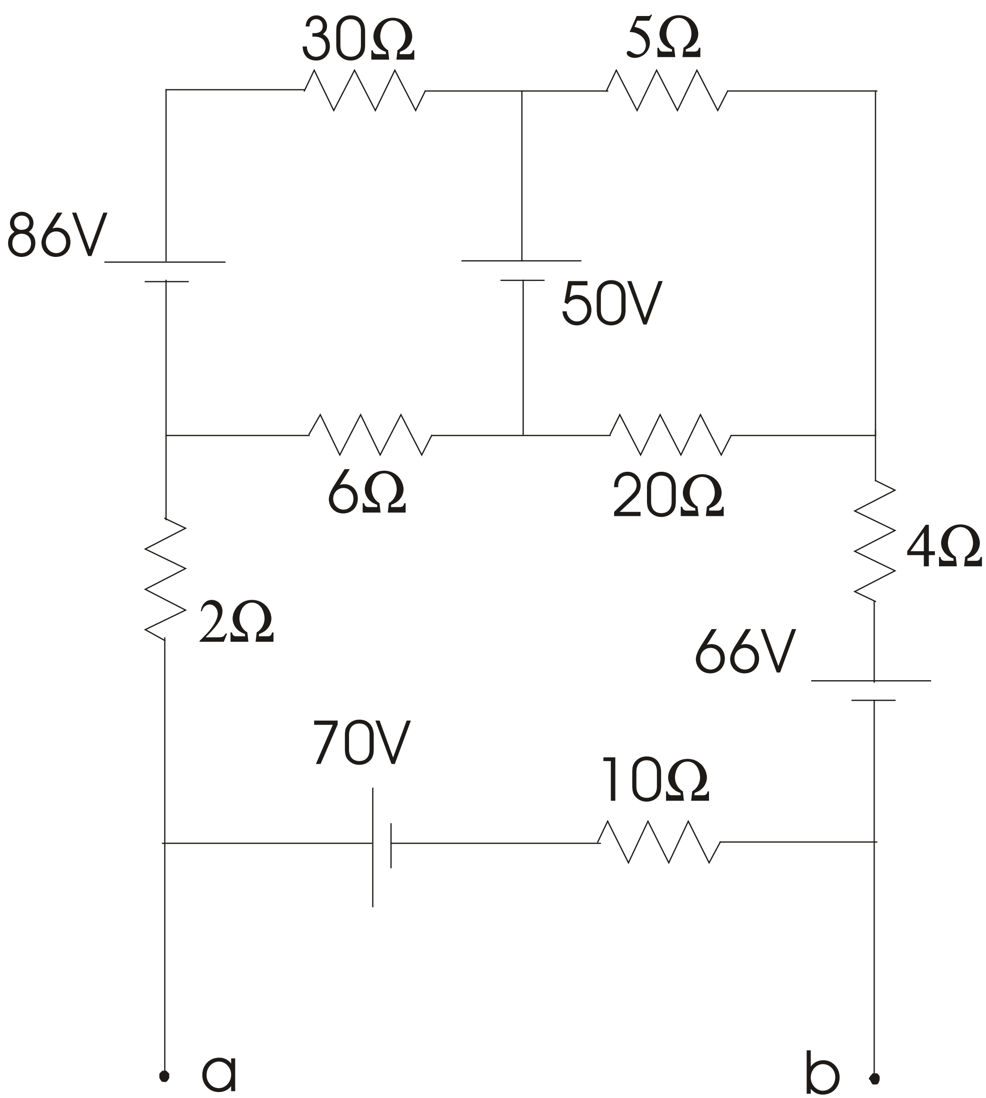
$$\Delta_R \equiv \begin{vmatrix} R_{11}R_{12}\dots\dots\dots R_{1n} \\ R_{21}R_{22}\dots\dots\dots R_{2n} \\ \dots\dots\dots \\ R_{n1}R_{n2}\dots\dots\dots R_{nn} \end{vmatrix}$$

Thévenin theorem

Any two-terminal network of resistance elements and energy sources is equivalent to an ideal voltage source V_T in series with a resistor R_T, where V_T is the open-circuit voltage of the network, and R_T is the equivalent resistance when all energy sources are turned off (short-circuit for voltage sources, open-circuit for current sources).



1st step: theoretical circuit solution



1. Find mesh currents
2. Determine V_{ab}, Thévenin voltage
3. Reduce voltage sources to zero by short-circuiting them and calculate equivalent resistance across points a and b, Thévenin resistance

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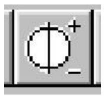
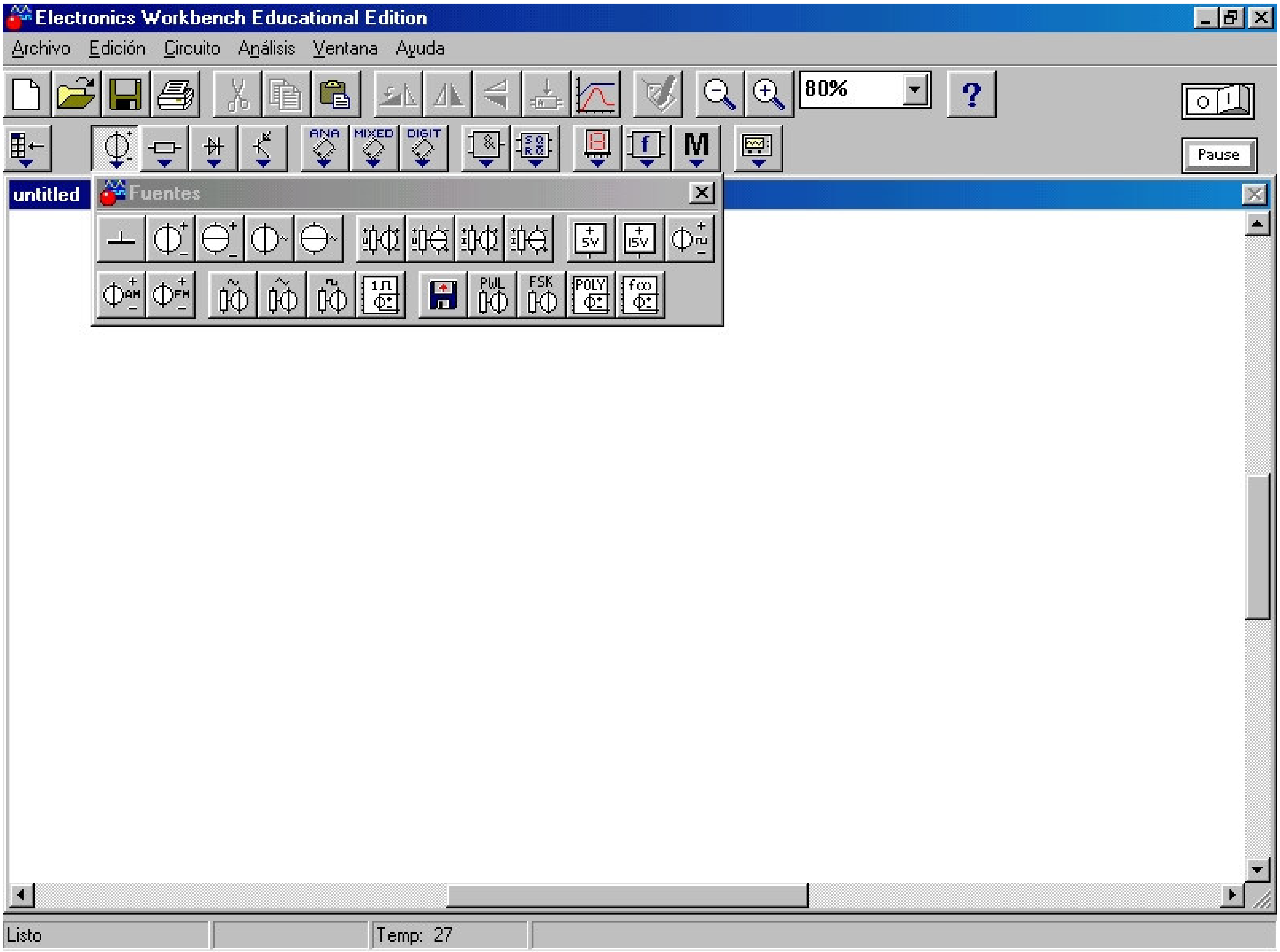
2nd part: Simulation with *EWB*





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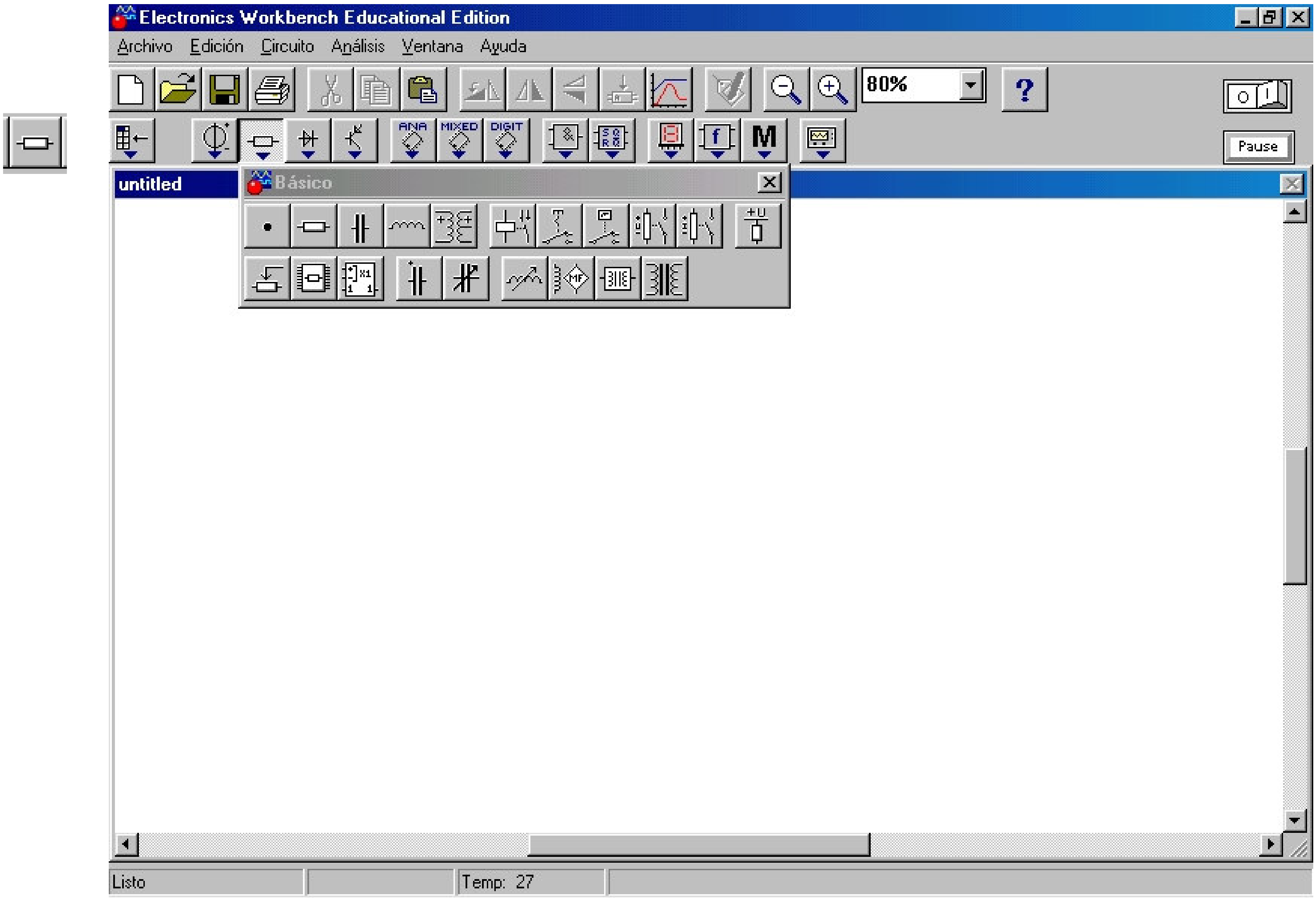

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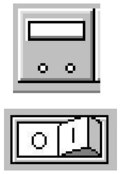

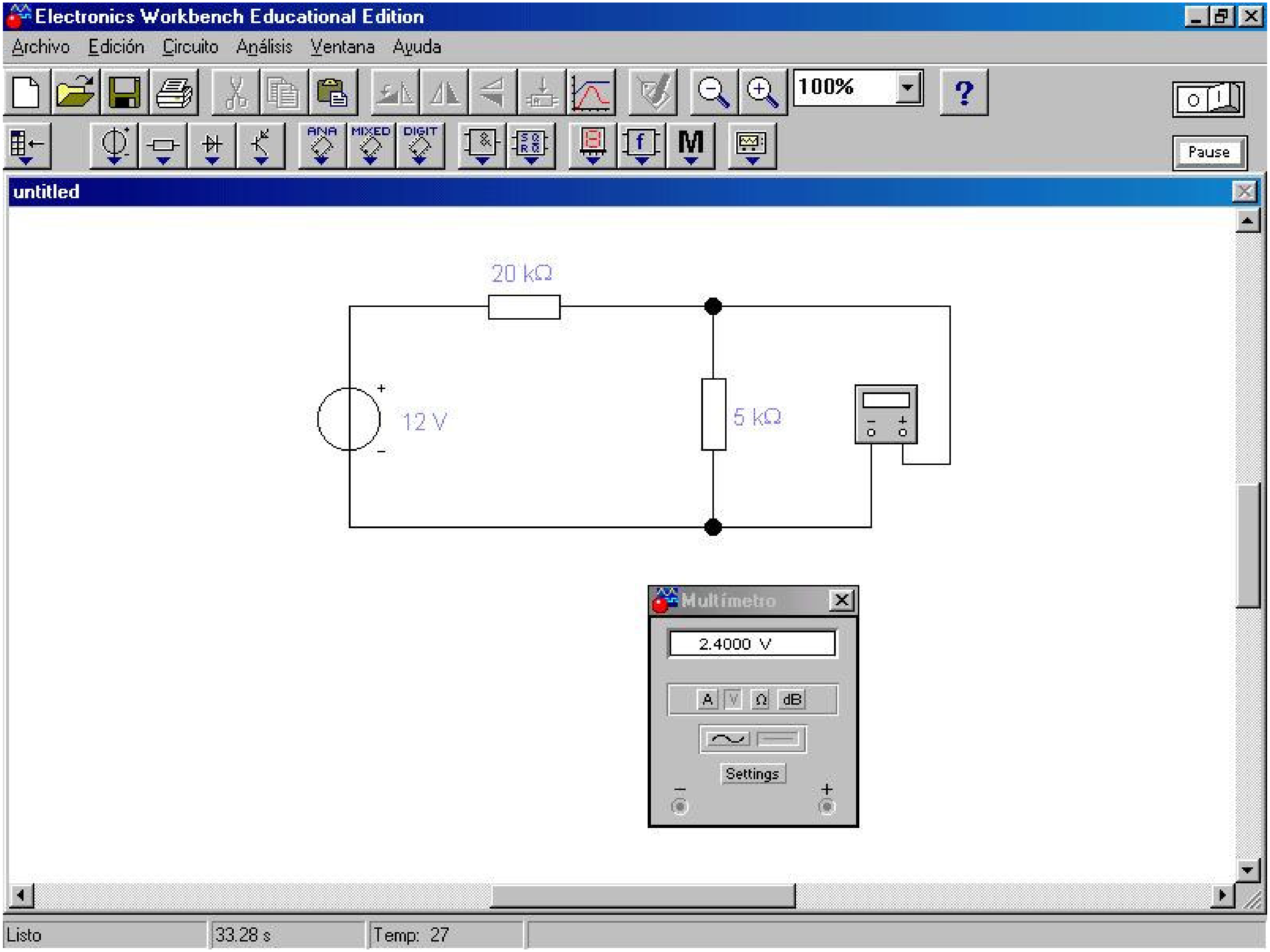

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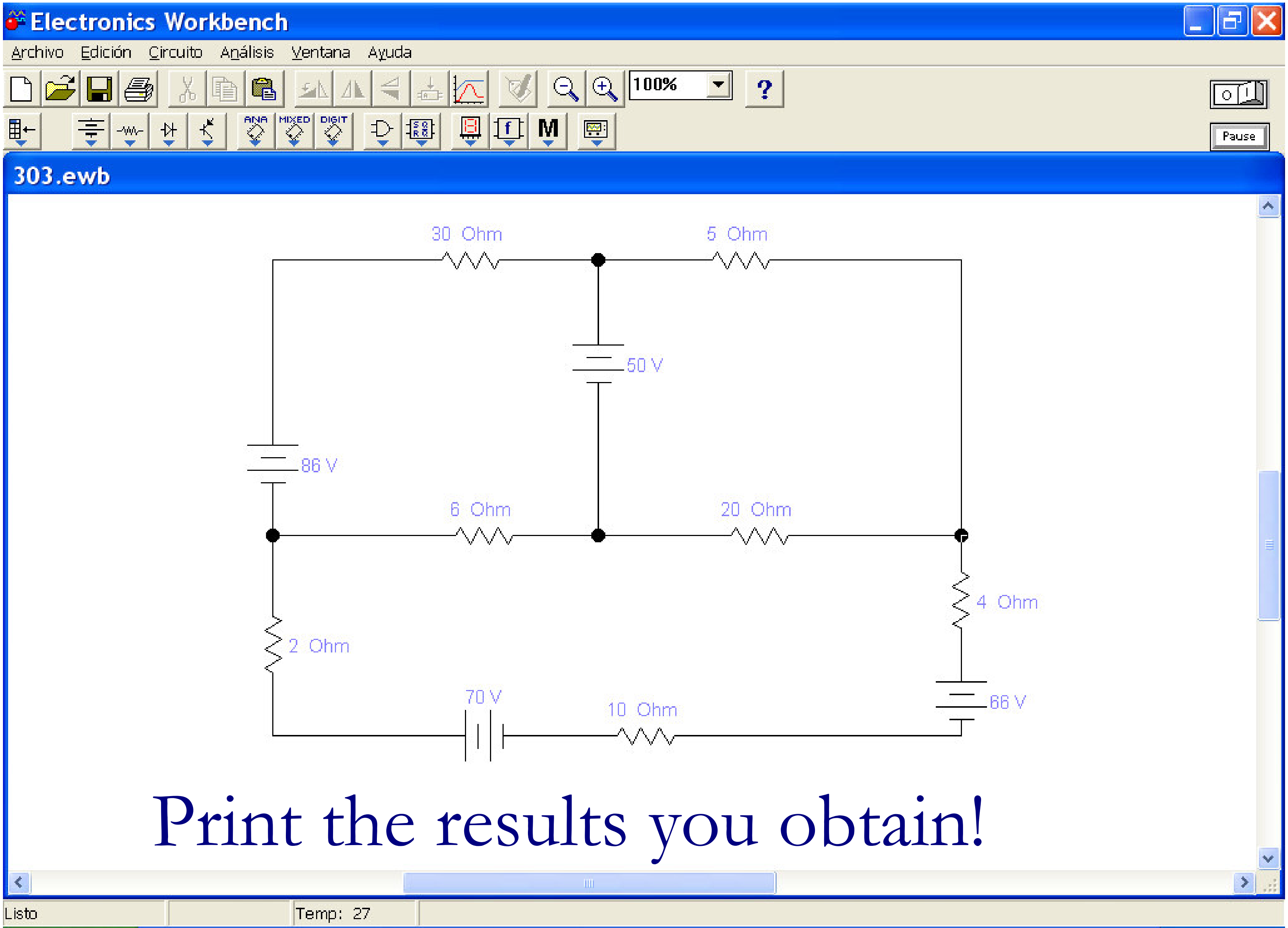

Print the results you obtain!